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The Leading Edge Vortex: a bio-inspired design enhancement for marine current turbines

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1. Motivation

The predictability and high power densities of tidal flows have long been recognised. Yet tidal stream energy has not lived up to its energy generating potential given the complexities of operating within the marine environment. Combinations of high power densities, finite water column heights, wave-current interactions and rough sea beds result in complex, sheared and highly turbulent, three-dimensional flow as shown in *Figure 1*.

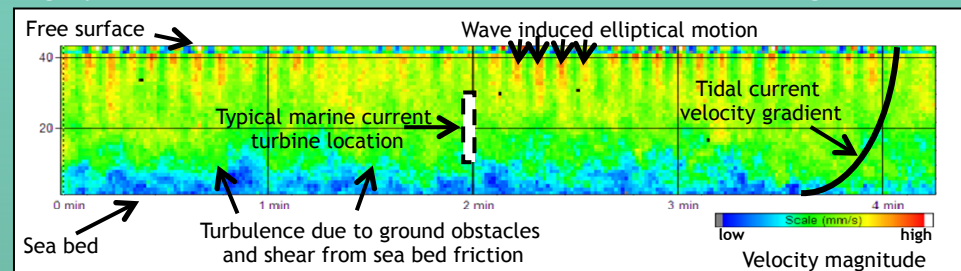


Figure 1: Typical flow field experienced by a marine current turbine, coloured by velocity magnitude. Image edited from Garrad Hassan (2012)

The turbine blade experiences:

- Velocity fluctuations and rapid changes in angle of attack due to wave-current interaction and turbulence. These result in lift fluctuations and potentially stall, so present rapid and significant loading fluctuations at the blade root;
- Further cyclical lift as the turbine blades rotate through different levels of the boundary layer, which present a velocity profile;
- Diurnal tidal flow reversal, where at increasing velocities the boundary layer becomes increasingly sheared.

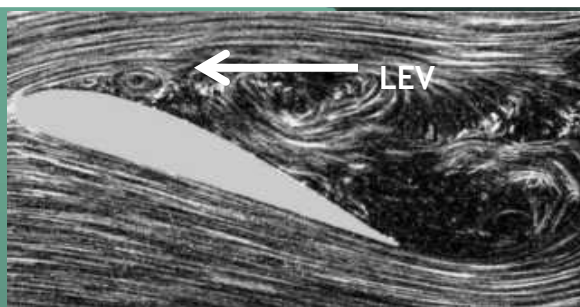


Figure 4: Dynamic stall over an airfoil. The flow has separated at the leading edge where a leading edge vortex (LEV) can be seen.

3. Theory

The key mechanism allowing birds and insects to fly has only recently been identified - the Leading Edge Vortex (LEV).

The LEV is a key component of dynamic stall (*Figure 4*) - a process which is common to any airfoil experiencing the rapid and large angle of attack variations which are present for both tidal turbine blades and insect or bird wings. It is characterised by a fast flowing vortex (the LEV) generated at the leading edge. This vortex travels downstream over the wing providing augmented lift, before it is shed and the wing experiences normal stall.

For birds and insects the LEV remains attached to the leading edge providing sustained lift generation, and is stabilised by span-wise vorticity transport. A stable LEV is also used to generate lift on delta wings, and the parallels between these two cases have been highlighted, particularly at higher Reynolds Numbers. While LEV stability on delta wings is largely understood, research in to the stabilising transport mechanism on the wide range of wing kinematics and geometries of biological fliers is in its infancy, but gathering significant attention e.g. *Fig 5* compares flapping (rotating) to soaring (translating) wing aerodynamics.

4. Aim

Vorticity transport is key in LEV stabilisation. This research aims to deliver a phenomenological model for the prediction of flow over a wing, depending on geometry and flow conditions. Thereby allowing the exploitation by design of the valuable high lift mechanism that is the LEV, by existing or novel applications.

Objectives:

- Unify understanding of vorticity transport mechanisms
- Test effect of increasing blade / wing length on vorticity transport
- Expand current understanding to high Reynolds Number conditions

2. Inspiration

In order to better design an energy extracting device tuned to the complexities of the tidal environment we can look for similar flows within nature and the biological flyers that have evolved to cope within them. Interestingly, background turbulence levels experienced by insects and birds (accounting for scale), are comparable with those experienced in a tidal channel (see *Figure 3*).



Figure 2: A fly is able to lift a frog using vortex lift (honest...)

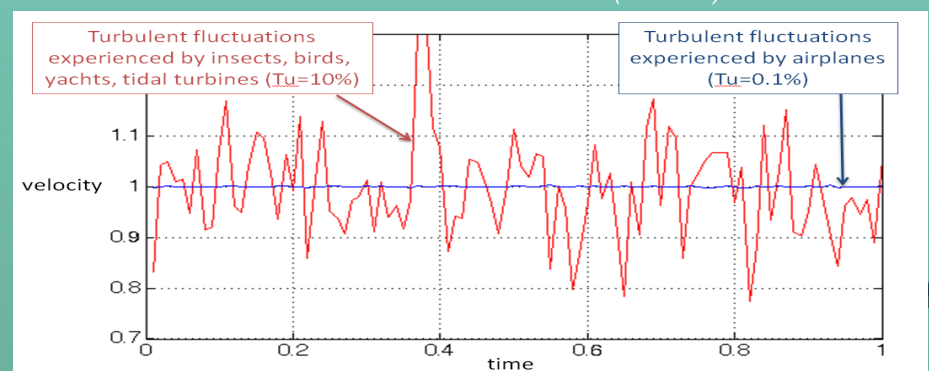


Figure 3: Comparisons of background turbulence experienced by tidal turbines with that of other lift reliant fliers

Insects and birds successfully generate significant and sustained lift in complex and turbulent flows where ground obstacles and topography can create strong eddies and vortices.

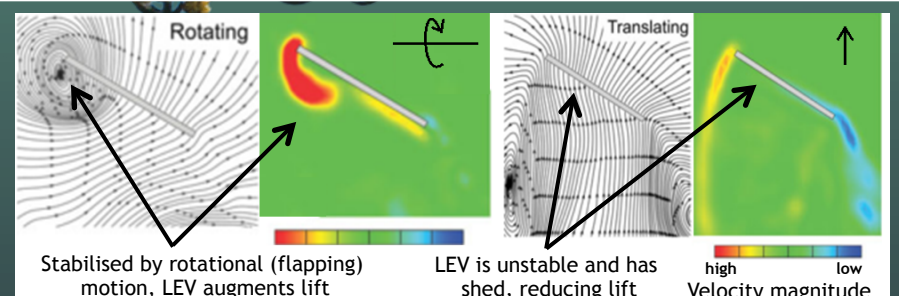


Figure 5: Flow around a plate with and without stable LEV